

Modeling Ecosystem Integrity: Decision Tools for Prioritizing Stream Restoration

William Kleindl, Lucinda Tear, Chip Maney, Pete Lawson and Bill LaVoie
Parametrix, Inc

Abstract

Stream restoration projects are increasing at unprecedented rates in the Puget Sound region. To allocate limited resources effectively, projects must be prioritized using best available science. To assist in prioritization of restoration projects in multiple drainages, an aquatic habitat assessment model was developed for Snohomish County, Washington, USA. We developed an ecologically based decision tool that was (1) appropriate in scale, cost-effective, and management focused, and (2) used regional reference data to compare sites and detect degraded conditions. The result was a multimetric habitat model called the “index of habitat integrity” (IHI). The development of the IHI included an assessment of over 60 different physical habitat attributes (e.g. woody debris, unstable banks) sampled in drainages that varied in degrees of human disturbance as measured by different land cover attributes (e.g. impervious area, forest cover). Physical attributes that changed in predictive ways with increased human influence provided meaningful indicators of habitat response to perturbation. Six habitat metrics, which met the qualification, were combined into the IHI model. The IHI model is used in conjunction with the benthic index of biotic integrity model (B-IBI) as a restoration prioritization decision tool.

Introduction

In 2002, Snohomish County, Washington, USA, conducted a drainage needs assessment of the aquatic resources condition of seven drainage areas that are influenced by the County’s Urban Growth Areas (UGA). The outcome of this assessment were several drainage needs reports (DNR) that provided a list of potential Capital Improvement Program (CIP) projects that would be implemented to maintain or improve stormwater conveyance, water quality, and habitat conditions as these drainage areas progress toward urban build-out. To assist the County in prioritizing habitat projects, the drainage needs assessment project developed a habitat-based model that will help assess the response of habitat to impacts from growth in the UGAs in a manner that will assist in the prioritization of habitat CIP efforts amongst multiple drainage areas. A more detailed description of the drainage needs assessments for Snohomish County is available in the County’s document: *Aquatic Habitat Summary: Current and Future Conditions of Urban and Urbanizing Streams of Snohomish County* (Snohomish County 2002a) and other DNR documents available on the County’s web site (<http://www.co.snohomish.wa.us/publicwk/swm/drainage/dnr/index.htm>).

States and counties throughout the nation are challenged with developing habitat assessment tools that are appropriate, cost-effective, and can translate scientific data into sound management decisions regarding water resources (Barbour *et al.* 1999). Barbour *et al.* (1999) state in their Rapid Bioassessment Protocol (RBP) that the approach to analyzing biological and ecological data should be straightforward to facilitate a translation into management applications. RBP emphasizes that this approach is not meant to reduce the rigor of data analysis, but to ensure its place in making crucial decisions regarding the protection, mitigation, and management of the nation’s aquatic resources. This general modeling philosophy, to develop a tool that is appropriate to the scale of the project, cost-effective, and management focused, was the first of two principles that guided the development of this project’s modeling effort.

The second principle that guided the project’s model development was the use of reference conditions. A reference condition establishes the basis for making comparisons and detecting perturbations, and should be applicable on a regional scale (Gibson *et al.* 1996). Snohomish County has data from both UGA streams from the current DNR project and data from surveying efforts in rural and forested stream systems. These data provided the means for comparing the habitat conditions of urban and non-urban stream systems. Please note, however, that these reference streams are not pristine and do not necessarily provide either *suitable* or *properly functioning* habitat. They simply represent the best habitat conditions available within the Snohomish County, USA habitat dataset.

The RBP defines a modeling approach that is based on assessing how attributes of a stream system diverge from a reference condition (Barbour *et al.* 1999). The RBP literature describes both multivariate and multimetric modeling approaches that can be used to develop habitat assessment tools that are easy to translate into management actions and that are based on reference conditions.

The River Invertebrate and Classification System (RIVPACS) (Wright 1993; Clarke *et al.* 1996; Hawkins *et al.* 2000; Hawkins and Carlisle 2001) is an example of a *multivariate method* that has been used in a variety of habitat assessment projects. The Benthic-Index of Biotic Integrity (B-IBI) (Fore *et al.* 1996; Karr and Chu 1999; Kleindl 1995) is an example of a *multimetric method* that has been used to assess biotic condition of stream systems in the Puget Sound lowlands. Both models used similar approaches in their development. Both approaches begin by classifying reference sites into biologically similar groups (using cluster analysis or professional experience). Then both calculate the environmental variables that best discriminate among these groups of biologically similar sites across a land use gradient. Multivariate models such as RIVPACS then compare the number of attributes (taxa for that model) observed at the test sites with the number expected at reference conditions and use this information to recommend preservation of sites with high observed-to-expected ratios and restoration of sites with low observed-to-expected ratios. Most of the literature that discusses the multivariate method emphasizes that a large number of reference sites that include a great deal of habitat diversity are required for this method to be robust.

A multimetric index provides a means of integrating information from a selection of meaningful habitat attributes into a composite score. For this project, the multimetric approach described by RBP proved the most fruitful approach to developing an intuitively clear model that could provide tools for understanding why drainages were rated as they were and assist in prioritizing the multi-drainage CIP effort. Multivariate methods were used to complement the multimetric model and validate the usefulness of the metrics selected for discriminating between reference and less high quality habitats.

The modeling technical team examined several local and national models developed to assess habitat quality and found that the first and most frequent use of these models has been to predict the standing stock of individual target species of interest (usually game fish) by defining limiting factors so that constraints to target species production can be eliminated (Binns and Eiserman 1979; Platts *et al.* 1983). The second most common use of habitat indices has been to assess the minimum or optimal flow that would protect habitat of target species (Bovee 1982 and 1986). A third type of habitat assessment technique focuses on aquatic community responses, rather than species-specific responses, to changes in habitat quality (Rankin 1995). This type of index establishes reference habitat and biotic conditions and ranks sites with respect to these conditions.

The index developed for this model assesses the physical integrity of a stream system and is intended to be used in conjunction with the B-IBI as an additional tool for resource management. For the purposes of this document, the multimetric habitat model will be called the Index of Habitat Integrity, or IHI.

Methods

As described above, a multimetric approach was taken to develop a habitat index that describes a range of habitat quality and how habitat quality is affected by land use in Snohomish County. The following steps summarize how the IHI was developed.

Drainages Used in Model Development

Reference drainages were defined as drainages with greater than 13% mature evergreen forest. These drainages represent the best available conditions within the data set available for this effort, but may not represent the best available conditions in all watersheds in the Puget Sound lowlands. The DNR areas (not reference conditions) are the drainages of interest by the County for the CIP development. This list includes Lake Stevens data collected in 2000. The remainder of the sites were surveyed in 2002. Also included in the list are two of the larger drainages within Swamp Creek and North Creek DNR areas. Finally, the remaining drainages in the data set were surveyed, with the reference drainages, by Snohomish County, USA in an effort unrelated to the DNR project. These drainages provide information for areas of land cover between the forested and urban sites.

Collect Instream Habitat Data

Instream habitat data used in the model were collected within a sampling domain that represented a gradient of anthropogenic disturbances. The sampling domain for this project was third- through fifth-order streams in Snohomish County, USA and included the urban streams of the DNR study area and forested streams outside the DNR study area. These data provided the means to compare the relative habitat conditions in urban and forested stream systems. The methods for collecting the habitat data were *Physical Habitat Survey and Monitoring Protocol for Wadeable Streams Version 6.1* (Snohomish County 2002b) for the DNR/CIP project and *Version 6.0* for the non-DNR study. Version 6.1 methodologies are described in Section 2.2.4. In cases where data collected by the two methods were not consistent, those data were not included in the model development. For example, version 6.1 measured riffle length to make

assessments of pool, riffle, and run/glide ratios, while version 6.0 does not. Therefore, these data were not considered in the complete analysis.

Select Physical Attributes for Use in the Model

Data describing a large number of variables were collected in the field, and summary statistics were computed for each habitat attribute (variable). Approximately 63 physical attributes were derived from these survey data. Several of these were normalized to control for differences in stream size and the length of the stream segment that was surveyed. For example, the percentage of sampled stream bank that was found to be modified was used in analyses as opposed to the absolute length of modified banks.

Select Metrics from the Physical Habitat Attributes that Best Discriminate Between Reference Sites and Stressed Sites

We then evaluated the instream habitat variables to determine which were most useful for distinguishing between reference and stressed sites. Reference sites represent the best available habitat conditions within the sampling domain. In this study, reference sites generally correspond to the non-DNR, non-urban study streams with a surrounding land cover dominated by mature evergreen forest and low impervious area. Stressed sites are the anthropogenically impacted streams and generally correspond to streams within the DNR areas with low percent mature evergreen forest and high impervious area. We used land cover attributes as indicators of reference and stressed sites. Land cover data were provided by Snohomish County, USA (Snohomish County 2002a) and included land cover variables in Table 1.

Table 1. Land cover data developed by Snohomish County.

| | |
|---|--|
| High impervious area | Mixed forest |
| Medium impervious area | Mature evergreen forest |
| Total impervious area (= High Impervious area + 0.5*Medium Impervious area) | Total Forest (= Mature evergreen forest + Mixed forest) |
| Crops/grass | Open water |
| Marsh | Unclassified |
| Scrub/shrub | Unknown |

We looked for habitat variables that fit the definition of a metric. “A metric is a physical attribute that changes in some predictable way with increased human influence” (Barbour *et al.* 1995). A good habitat metric would provide a meaningful indicator in assessing the habitat response to perturbation (Barbour *et al.* 1999). Metrics should be ecologically relevant, sensitive to stressors, and provide a response that can be discriminated from natural variability. To determine the most useful metrics, we examined relationships between habitat variables and land cover variables. These relationships were explored to find the land cover variable that was correlated with the greatest number of potential habitat metrics. Land cover metrics used to distinguish reference from stressed sites may not always be the best general indicators of “disturbance” or provide the highest explanatory power in a quantitative model.

Scoring the Metrics and Creating a Multimetric Index

An index provides a means of integrating information from a composite of various habitat attributes (Barbour *et al.* 1999). Each of the habitat metrics varies in scale, or may be presented as ratios, percentages, or area. Therefore, before developing an integrated index for assessing habitat conditions, it is necessary to standardize the metrics by transforming them to unitless scores that use the same scale. Figure 1 provides an example of a scored metric. The scores range from 1 to 5 and provide a means of qualifying the conditions related to the metric, 1 being *poor* and 5 being *excellent*. The scores from each metric are summed to create the IHI. Scores for each habitat metric were determined based on the distribution of values of the habitat metric itself, not on a quantitative relationship between the habitat metric and land cover variable. Scores were determined based on visual assessment of the metric’s distribution that considered the range and continuity of the data, regulatory criteria, and best professional judgment of what constituted meaningful ecological differences.

Confirming the Multimetric Index

The habitat index scores were then plotted against percent mature evergreen forest (PMEF) and total impervious area (TIA) to understand how the final index was related to the two explanatory land cover variables. A linear regression

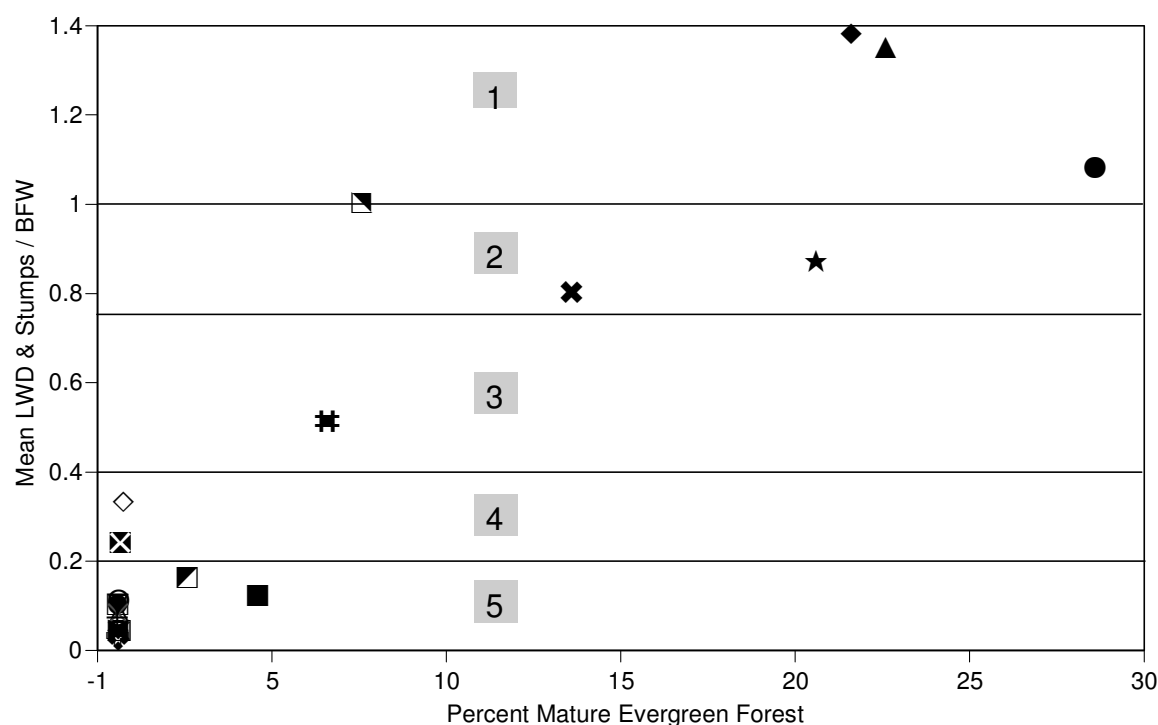


Figure 1. Metric Scoring Example.

was fit to both relationships, the slopes were tested for significance, and the residuals were examined to see if they were normally distributed around the model. Several nonlinear models were fit if the linear model did not seem valid.

If the relationships between the IHI scores and land cover variables are significant, then the IHI scores can be used to predict average habitat condition along the range of land cover conditions.

Model Validation

Bootstrap methods were used to investigate the variability in the IHI score for each drainage. We randomly re-sampled, with replacement, the data collected from the sampled reaches in each basin. Each bootstrap sample is treated as if it were a new set of field data, and an IHI score for the basin is calculated from that sample of reaches.¹ Because the initial field sample of reaches was a random sample that represented the range of variability in a basin, multiple bootstrap samples from that sample provide an idea of how variable IHI scores in a basin could be if additional field samples were taken. The width of a bootstrap confidence interval, in this case the range of values between the lower 5th percentile and the upper 95th percentile, provides a quantitative measure of the variability in IHI scores that could be expected within a basin. Basins with narrower bootstrap confidence intervals have lower variability in habitat conditions than basins with wider confidence intervals.

If the variability in IHI scores within basins appears to be greater than the variability in IHI scores across basins and, therefore, across a range of land cover conditions, then the IHI approach would not seem to be helpful for predicting habitat quality from land cover conditions. If, however, variability within basins is less than variability across basins, then the IHI model would appear to be supported.

Comparison with B-IBI Model

The B-IBI is a regionally accepted model that measures the health of the biotic condition of a stream. This multimetric model was developed in a similar manner as the IHI model. Collectively, the information provided by the two models would be very helpful in CIP decisions. However, first it was important to determine if these two models provide compatible information.

The DNR habitat assessment team collected macroinvertebrate data from each DNR study stream to generate a B-IBI score for the drainage. The sample number (n) from this effort was small and represented only a small range of land cover conditions, so it was not possible to compare models of B-IBI and IHI relationships for all of Snohomish County data. B-IBI data were available, however, from the broader population of streams throughout the Puget Sound lowlands from other sources within in Snohomish County, the internet (www.Salmonweb.org) and local master degree efforts (Kleindl 1995; Morley 2000). Linear and nonlinear models were fit to these B-IBI data, and the slopes of the linear models of the relationships between total impervious area, B-IBI, and IHI scores were compared using Analysis of Covariance (ANCOVA).

Results

Model Development

Selected Habitat Metrics

A total of 63 habitat attributes were collected in 22 surveyed basins. Scatterplots of basin-averaged habitat attributes against different land cover variables were created and sorted to determine the land cover variables that showed the strongest relationships with the highest number of habitat variables. Percent mature evergreen forest (PMEF) was the land cover variable that met this criteria. Therefore, PMEF was selected as an explanatory variable to guide scoring of the habitat metrics. The final set of six instream habitat metrics was:

- **Percent Fine Sediment.** As the PMEF in a watershed decreases, sediments in the system become unstable and more fines enter the streams. With high PMEF, fines are rarely found in spawning gravels while at 0 PMEF, a wide variety of percent fine conditions can be found (Figure 2). The curvilinear response of fine sediment to urbanization and the increase in variance as PMEF decreases may indicate that different processes are responsible for low percent fines in some highly urban streams (e.g. all fines have been washed from the system) than in less developed streams where fines are still being redistributed.
- **Percent Hydro-modified Banks.** In less developed streams, hydro-modification rarely occurs. However, like percent fines, there is a wide range of conditions in the urban streams. The Pilchuck River was not shown in Figure 2 because it is 49% hydro-modified, while the others are less than 10%.
- **Percent Unstable Banks.** This metric indicates that as streams become more developed, there is an increase in unstable banks, however, as with the other metrics, variance is high across highly urbanized streams. In urban streams, unstable banks are often replaced with hydro-modifications (Figure 2).
- **Percent Pool Functional Area.** The literature suggests that percent pool area is very important for salmonid habitat. However, the majority of the streams surveyed, even the reference conditions, had less than 35% pool area (see Figure 2) and the relationship with PMEF was not clearly linear.²
- **Pools/BFW.** This metric showed a strong relationship with PMEF; pool density decreased as streams became more developed (Figure 2).
- **LWD and Stumps/BFW.** This metric showed a strong relationship with PMEF; wood density also decreased as streams became more developed (Figure 2).

Plots of the metrics against PMEF were helpful in determining meaningful scoring criteria (Figure 2). The final scoring criteria for each metric are shown in Table 2.

Table 2. Physical Metrics, Response to Human Disturbance, and Scoring Criteria Used to Integrate into IHI Multimetric Index.

| Metric | Response to Human Disturbance | Scoring Criteria | | | | |
|------------------------------------|-------------------------------|------------------|--------------|--------------|--------------|----------|
| | | 1 (Poor) | 2 | 3 | 4 | 5 (Best) |
| Percent Unstable | Increase | > 4.6% | | 2 to 4.6% | | <2% |
| Percent Hydro-modified | Increase | > 8% | 6 to 8% | 4 to 6% | 2 to 4% | <2% |
| Percent Fines (No Pools = 0) | Increase | > 50% | 30 to 50% | 15 to 30% | 7.5 to 15% | < 7.5% |
| Total Percent Pool Functional Area | Decrease | < 5% | 5 to 10% | 10 to 15% | 15 to 20% | > 20% |
| Pool/BFW | Decrease | < 0.06 | 0.06 to 0.12 | 0.12 to 0.16 | 0.16 to 0.20 | > 0.20 |
| LWD and Stump/BFW | Decrease | < 0.2 | 0.2 to 0.4 | 0.4 to 0.7 | 0.7 to 1.0 | > 1.0 |

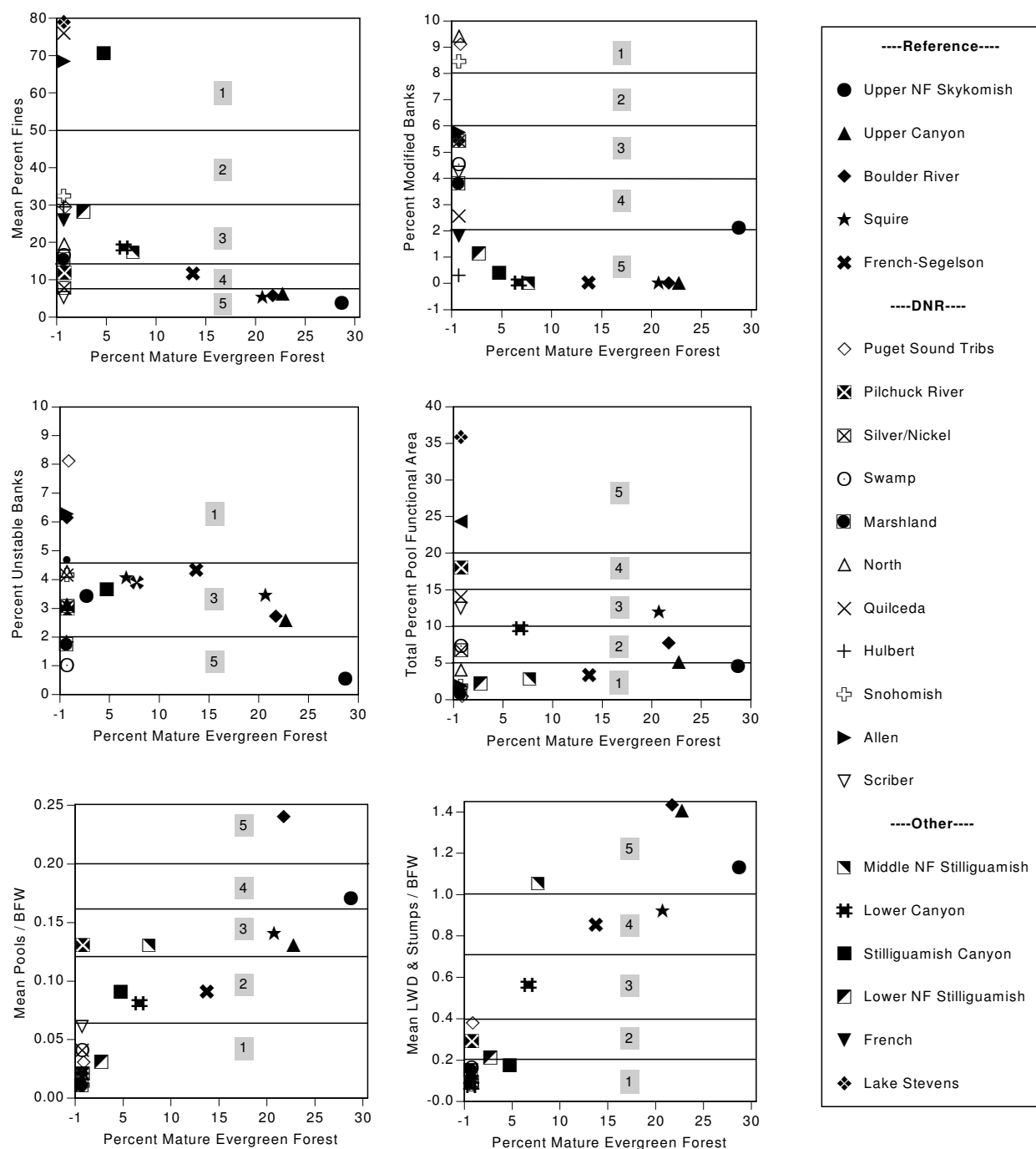


Figure 2. Scatterplots showing scoring of Basin-level Habitat Metrics.

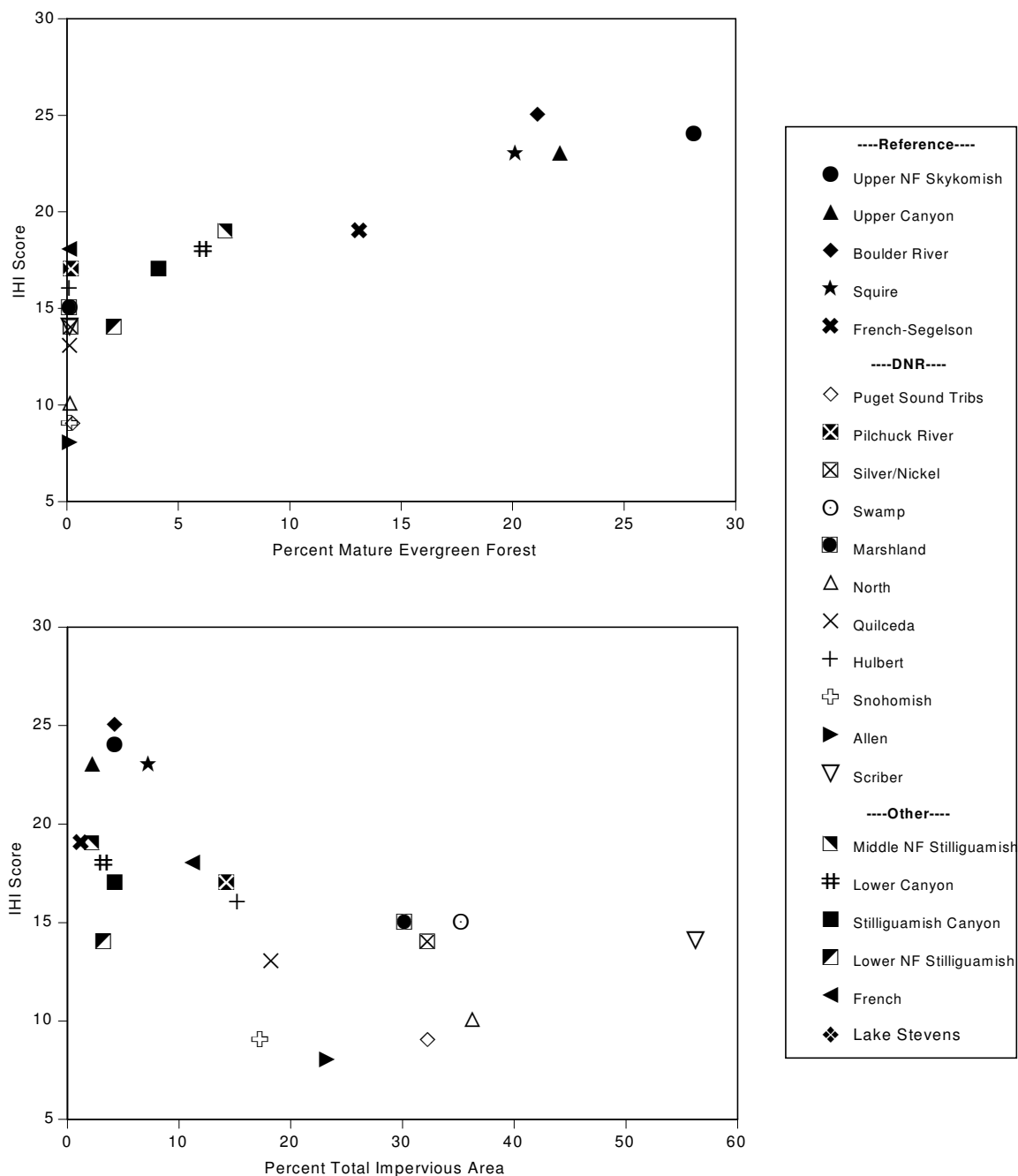


Figure 3. IHI Plotted Against PMEF and TIA.

For each basin, the scores of all the metrics were summed to create the IHI. Each metric is treated equally, and none are weighted. The index scores were plotted against PMEF to ensure that the model was providing the results that were expected along that land cover (Figure 3). However, it is generally recognized that total impervious area (TIA) is a convenient means of viewing human alteration within a watershed and is easily understood by the public, engineers, and decision-makers. Therefore, in Figure 3, the IHI results are also plotted over TIA to develop the final model of how habitat quality is affected by land cover changes associated with increasing urbanization in a manner that could be used to estimate habitat quality under different build-out scenarios.

The IHI allows decision-makers to assess the habitat conditions of a drainage relative to those streams with the best habitat in the County. The tool also can be used to determine if the average habitat conditions of a given drainage are better or worse than expected, given the general relationship between habitat conditions and land cover in the County (Figure 4). This information about the relative habitat quality of different basins can be evaluated in relation to general CIP goals to determine which basins and which types of CIP projects should be given a higher priority.

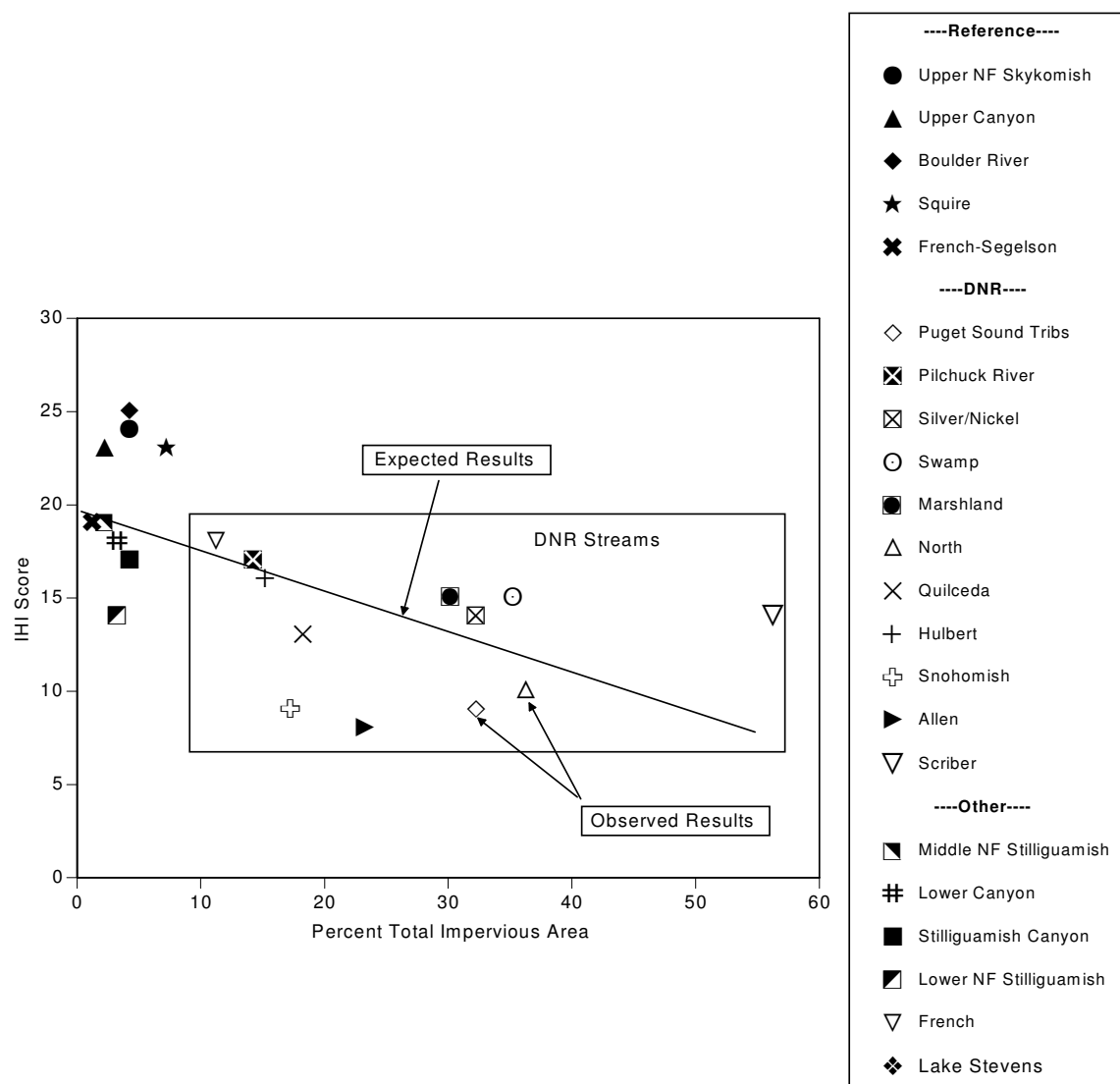


Figure 4. Habitat Integrity in Relation to TIA.

Figure 4 presents the results of the IHI model. The linear regression line describes the mean or “expected” IHI score for a given Percent TIA. DNR areas that fall below the TIA - IHI line have IHI scores lower than expected and areas with scores above the line have scores greater than expected, given their level of TIA. It should be noted that the coefficient of variation (r^2) of this regression is only 0.36. In other words, only 36% of the variability in IHI scores was explained by TIA. Obviously, many other factors affect the IHI in a basin but the direction and magnitude of a basin’s deviation from model expectations for IHI can provide insight into the type of CIP projects that would most benefit a basin.

It is worth noting that the exponential (curvilinear) model for the TIA - IHI data provided a slightly better fit to the data with a coefficient of variation (r^2) of 0.44. The curve described by this model suggests that habitat declines sharply in the lowest range (about 0 to 8%) of TIA, and that as TIA increases it has less and less effect on the habitat. However, it is important to understand the limitations of this sort of interpretation. While TIA is a convenient means of measuring human perturbations in the landscape, it does not describe the true range of these perturbations. For example, in the lower ranges of TIA, logging, farming, and mining (not TIA) likely cause the most prominent impacts to stream systems. At moderate levels of development, new construction, changes in riparian condition, or wetland cover usually create the most prominent impacts and at the highest levels of development, TIA itself is probably the best measurement of impacts. Over interpretation of the shape of the TIA - IHI model can be misleading and support the potential misinterpretation that TIA is the only and most important measurement of human perturbation. Table 3 shows the results of linear regressions of IHI against several other land cover measurements that could also be used to understand human impacts on the landscape.

Table 3. Measurement of variance (r^2) of IHI scores Vs. various land cover.

| IHI Variance with a Linear Regression Against the Following Land Cover: | r^2 |
|--|-------------------------|
| Percent Mature Evergreen Forest | 0.70 |
| Percent Total Impervious Area | 0.36 |
| Percent High Impervious Area | 0.27 |
| Percent Medium Impervious Area | 0.50 |
| Percent Urban Cover (High + Medium Impervious Area) | 0.40 |
| Percent Crops + Grass + Marsh | 0.44 |
| Percent Mixed Forest | 0.40 |

Validation of Model

Bootstrap Analyses

The width of the 90% confidence intervals gives an indication of the variability in habitat conditions within a basin; the confidence intervals are wider in basins that have greater variability in habitat quality among sampled stream segments.³ For example, Scriber Creek basin (56% TIA) had a wider confidence interval (i.e., a wider range of bootstrapped IHI values) than most other basins, indicating that it has a wider range of habitat quality in individual reaches than most of the basins (a small number of reaches was sampled in this basin as well). Swamp Creek (35% TIA) and Hulbert Creek (14% TIA) had low variability in IHI scores (narrower confidence bands) relative to other basins, and so may have more uniform instream habitat quality than other basins.

Confidence intervals developed from the bootstrap analysis indicate that potential sampling variability/error in basin IHI scores is small relative to the changes in IHI scores that occur across the range of TIA values in Snohomish County. That is, showing the potential variability in IHI scores for individual basins using the bootstrapped confidence intervals does not remove the sense that a relationship exists between basin IHI scores and their TIA or PMEF. The use of the bootstrap technique to provide information about potential variability within a basin and how that compares between basins helps to provide confidence that the IHI model is valid and insight into the kind of variability in habitat quality that may be expected to occur in basins with different geomorphic and land cover characteristics. These cross-basin differences do not seem to negate the existence of a relationship between the habitat integrity index and TIA and PMEF.

Comparison of Model Results with B-IBI Data

Comparison of IHI to B-IBI

The B-IBI data collected during the project and by other local sources have a linear relationship with TIA (Figure 5). B-IBI and IHI show similar relationships to TIA⁴. The two indices provide the same message: as urbanization increases, there is a measurable degradation of both instream biota and physical habitat integrity.

Discussion

The goals of the County's habitat efforts will determine which type of CIP projects are selected and the location of those projects. For example, if the County has decided to emphasize conservation CIP projects (via land acquisition), conservation projects in the basins with high IHIs could be given higher priority. If the County were to decide to try to raise the habitat quality of all basins below the expected IHI trendline to within some range of the expected habitat quality for a basin, restoration projects would be given higher priority. The program could also consider the expected IHI for a basin at build-out, compare that expected value to the current value, and select habitat improvement projects or other actions that may keep the current score from falling to the projected score.

For example, watersheds like Puget Sound Tributaries (IHI score of 9) and Marshland (IHI score of 15) have relatively similar TIA (30 to 32 percent). However, their IHI scores indicate that the habitat conditions of these watersheds are different. It would appear that instream habitat conditions in the Puget Sound Tributaries drainage has been degraded more than expected given the amount of development in the basin and that habitat conditions have been better preserved in Marshland than in other drainages with its level of development. Without considering future land cover conditions, CIP projects in the Puget Sound Tributaries drainage could be designed to improve physical conditions in the drainage, and projects in Marshland should focus on ensuring that further degradation does not occur as development continues. The choice between the two basins would depend on the goals of the capital improvement program. If one considers the land cover conditions that are projected to occur in the two basins, it may be that the Puget Sound Tributaries are

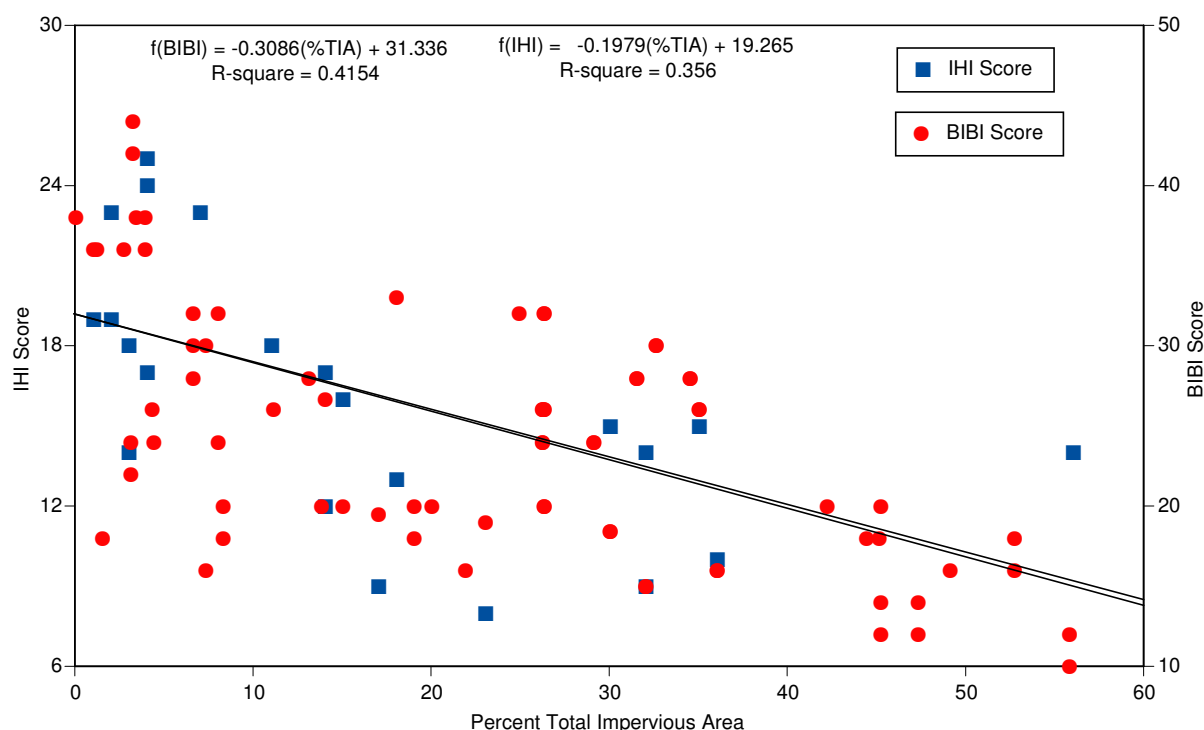


Figure 5. Comparison of regional B-IBI results with IHI scores.

expected to experience little additional development, while Marshland is expected to continue to develop. In this case, the preservation of conditions in Marshland might be given higher priority.

The B-IBI model provides complementary pieces of information to the IHI model about the quality of Snohomish County, USA streams. They should be used in combination to determine what types of CIP projects may best improve the biotic integrity of a drainage. For example, if the observed IHI score for a drainage is higher than expected for its TIA, and the observed B-IBI score is lower than its expected value, one could investigate the possibility that water quality or hydrology, and not habitat quality, was limiting the biotic integrity of the basin (Figure 6). Likewise, if the observed B-IBI was higher than expected and the observed IHI lower than expected, one could investigate whether water quality was better than the water quality in other drainages with similar TIA. CIP projects could then be given higher priority by considering what type of water quality, hydrology, or habitat improvement/conservation project would produce the best results for biota.

One note of caution should be expressed. The IHI model is made up of six separate metrics that measure individual habitat components. However, several of these components are affected by channel processes such as bedload movement, bank stability, and scour. Although removing hydro-modifications from streambanks will raise the score of the IHI, without repairing the process (or the human expectations for a stable channel) that caused the need for the hydro-modifications in the first place there may be further degradation to the stream. Once an area is selected through this prioritizing approach, the planning team should investigate both the local and watershed scale processes that will affect the CIP Project and select restoration, enhancement or conservation projects that are appropriate to the basin or reach scale for that drainage.

Next Steps

Combining multimetric models that assess biotic and aspects of the physical conditions take land managers one step closer to meeting the goal of the U.S. Clean Water Act: "To maintain the chemical, physical and biological integrity of our nation's waters." Work is currently being done in the State of Washington to take additional steps by developing a multimetric model to assess chemical conditions and other regional models are being developed to assess the impacts of hydrological conditions on ecosystems integrity. However it is important to remember the advice in the Rapid Bioassessment Protocol (Barbour *et al.* 1999) that the approach to presenting the analysis of biological and ecological data should be straightforward to facilitate a translation into management applications. Models that are easy to interpret

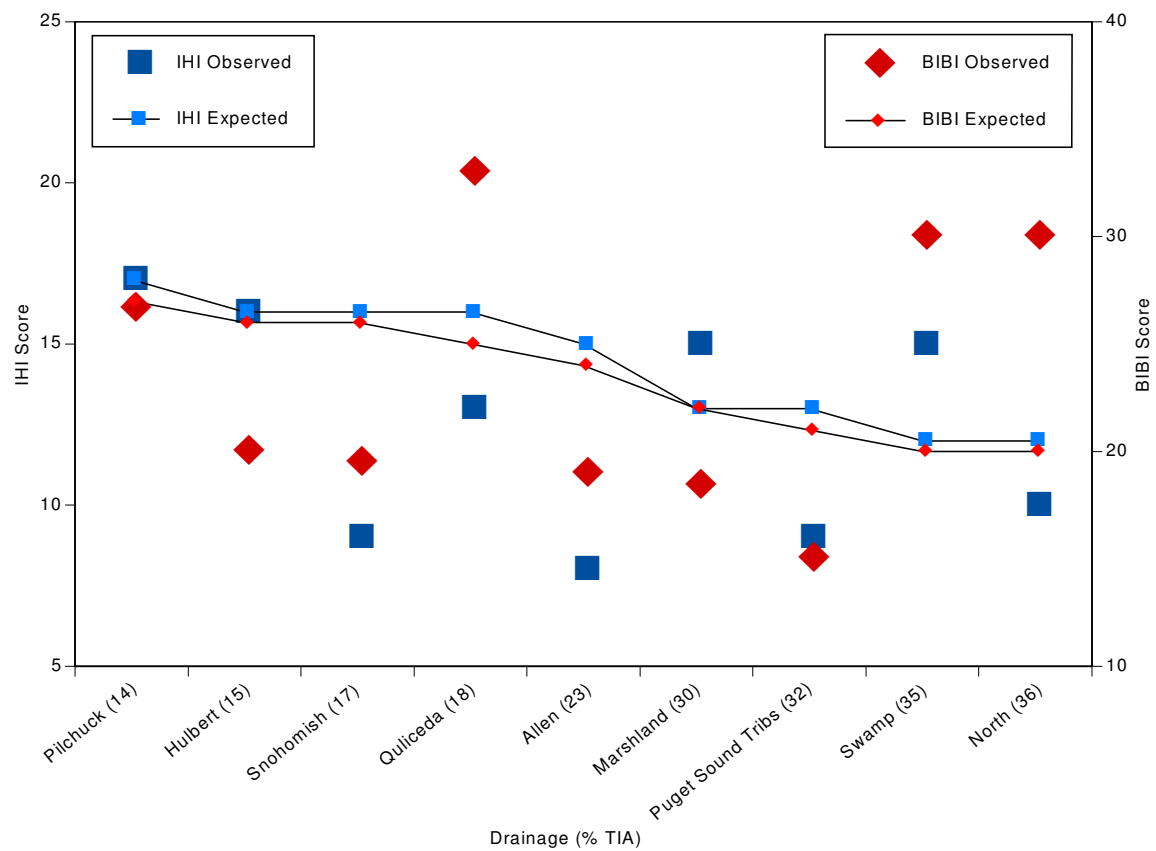


Figure 6. IHI and B-IBI observed and expected results.

and work in unison with one another will help managers to make ecologically sound decisions and direct their technical staff's efforts. As we create and work with models, we should keep in mind the underlying assumptions and hidden complexities of these models to ensure that thoughtful decisions are made and useful data are collected to expand our understanding and update our models.

Notes

- ¹ Bootstrap samples had the same sample size as the original sample. Because bootstrap sampling is conducted "with replacement," some reaches may be represented more than once in a bootstrap sample and others may not be represented at all.
- ² Note that the literature strongly supports the Percent Pool Functional Area as an important attribute for determining the overall health of salmonid habitat (e.g. Peterson *et al.* 1992, WDFW and Western Washington Treaty Tribes 1997). However, this attribute does not fully meet the criteria of a metric. It was included in the original development of this model and remains in this proceedings publication, but will likely be removed in future publications.
- ³ They also provide information about the statistical properties of the IHI (e.g., whether they tend to be normally or symmetrically distributed).
- ⁴ In fact, Analysis of Covariance indicated that there is no significant difference between the slopes of the two lines.

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